

## CASE STUDIES OF NOAA 6/TIROS N DATA IMPACT ON NUMERICAL WEATHER FORECASTS

Leonard M Druyan  
Dept. of Geography, Bar Ilan University  
Ramat Gan, Israel

Zvi Alperson and Tamar Ben-Amram  
Israel Meteorological Service, Bet-Degan, Israel

## 1. INTRODUCTION

The impact of satellite temperature soundings on numerical forecasts was reviewed by Ohring(1979) who summarizes that "The small average impact obtained is the result of a combination of positively influenced and negatively influenced forecasts and not the result of a consistent impact on each forecast." Moreover, "The small effect of the satellite data is also evidenced by almost all qualitative and synoptic evaluations of their impact." This appraisal has been sustained by Atlas et al.(1982) who determined by subjective evaluation of numerical prognostic maps that a significant improvement due to the assimilation of satellite data into the initial specification resulted in only a very small proportion of their case studies.

The above refers to the impact of satellite temperatures from systems which pre-date the launching of the third generation of vertical sounding instruments aboard TIROS N (13 Oct 1978) and NOAA 6 (27 June 1979). The first evaluation of soundings from TIROS N was reported by Phillips, et al.(1979) who found that oceanic, cloudy retrievals over NH mid-lattitudes show a cold bias in winter. Gruber and Watkins(1982) confirmed this for both satellite systems using a larger data base. They also showed that RMS differences between retrievals and co-located radiosonde observations within the swath 30-60N during the 1979-80 winter were generally 2-3K in clear air and higher for cloudy columns. This implies approximately the same error level as that summarized by Ohring(1979) for previous sensors.

Broderick(1980,1981) has reported two case studies which show a positive impact of TIROS N temperatures on the analysis of synoptic weather systems. In both cases analyses prepared from only satellite temperatures seemed to give a better definition to weather systems' thermal structure than that provided by corresponding NMC analyses without satellite data.

Thomasell, et al.(1983) summarized the results of a set of 14 numerical forecast experiments performed with the PE model of the Israel Meteorological Service (IMS); these were designed to test the impact of TIROS N and NOAA 6 temperatures within the IMS analysis and forecast cycle. Their study discusses the satellite data coverage over the NH, the mean area/period S1 and RMS verification scores and the spatial distribution of SAT versus NO SAT forecast differences. They find mixed results regarding the benefit derived from the satellite data although they conclude that positive forecast impact does occur over ocean areas where the extra data presumably improves the specification which is otherwise available from conventional observations.

Broderick(1983a,b,c) examined the forecast impact for three cases from the same set of experiments (1-14 Jan 1980). In one he found that satellite temperatures, some of dubious quality, observed over the Atlantic Ocean contributed to better forecasts over Iceland and central Europe although a worse result was verified over Spain. The second study showed that the better scores of a forecast based also on satellite data and verified over North America actually represented a mixed impact on the forecast synoptic patterns. His third case shows a superior 48hr 500 mb forecast over the western US due to the better initial specification afforded by satellite-observed temperatures over the north Pacific Ocean.

## 2. EXPERIMENTAL DESIGN

This report describes three case studies of satellite temperature impact (from NOAA 6 and TIROS N) on analyses and forecasts made by the IMS. The first of these is from the same group of experiments described above, the second is from another series (6-30 Jan 1979) which is during the special FGGE observing period and the third is from the series made for the period 20-27 Dec 1979. The experiments were made as part of a cooperative study in which NESDIS provided temperature retrieval data to the IMS; results are being analyzed both in Israel and at NESDIS. Satellite data observed over water and over north Africa were assimilated into the IMS objective analysis routine to create the initial conditions for 48hr numerical SAT forecasts by the IMS model. Analyses were made in parallel from non-satellite data sources and these initialized the NO SAT forecasts with which the first kind were eventually compared. The IMS model simulates atmospheric circulation by solving the primitive equations at five vertical levels on a cartesian grid (380km interval) which covers most of the NH. The model does not simulate the hydrological cycle nor does it account for diabatic heating.

## 3. CASE 1, INITIAL CONDITIONS 12GMT 13 JAN 1979

Figure 1 shows the significant differences in the initial conditions of the SAT and NO SAT analyses. The initial 1000-500mb thicknesses show that the satellite temperatures (observed within a time window of +3hr) have introduced a rather cold tongue over the central Atlantic Ocean which lowers thicknesses there by 60-90m as compared with NO SAT. This area is southeast of a 500mb vorticity maximum evident on both analyses (figures 2A, 2B) and it creates a sharper trough oriented northwest-southeast near 40W in the SAT specification. This also creates a broader area of positive vorticity advection (PVA) south of about 47N for the SAT atmospheric state at the hour of these initial conditions.

South of Newfoundland (30-40N, 55W) satellite temperatures have defined warmer thicknesses (figure 1) which are as much as 120m greater than those in the counterpart analysis. As a result, NO SAT puts a 500mb trough at 51W while SAT shows a shallower wave further east (figures 2A, 2B).

Large differences in the 48hr 500mb forecasts are outstanding over the eastern Atlantic Ocean. Additional penetration of the SAT cold tongue has brought a sharp 500mb trough to 20-25W while NO SAT predicts a shallow wavy 10° longitude further east (figures 3A, 3B). The SAT forecast heights along the trough axis (between 39-49N) are more than 180m lower than those predicted by NO SAT. The verification analysis (figure 3C) shows that the deepening of the trough by SAT north of about 40N is exaggerated giving heights 150m too low. NO SAT forecasts more reasonable heights but shows no indication of the troughing observed

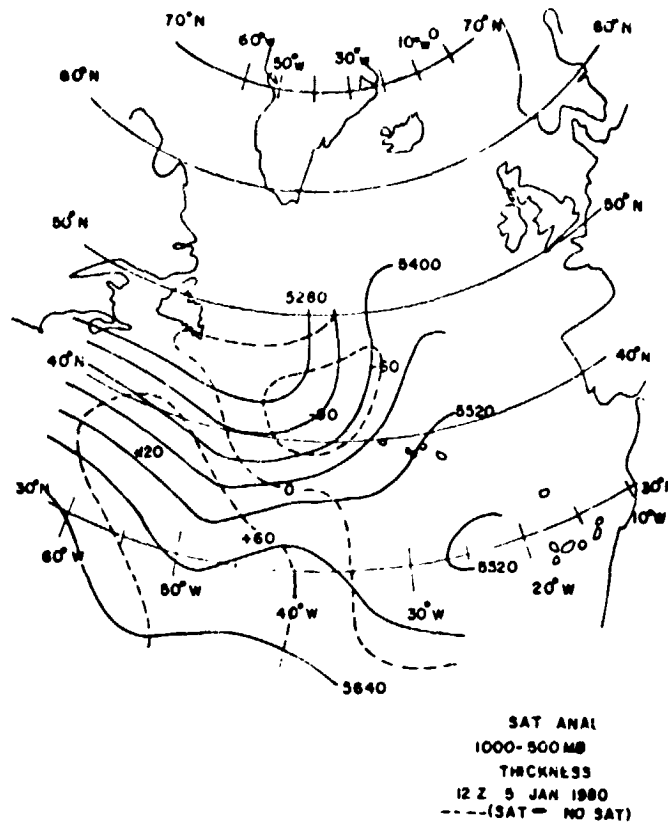


Fig. 1. Initial 1000-500 mb thickness and differences from NO SAT.

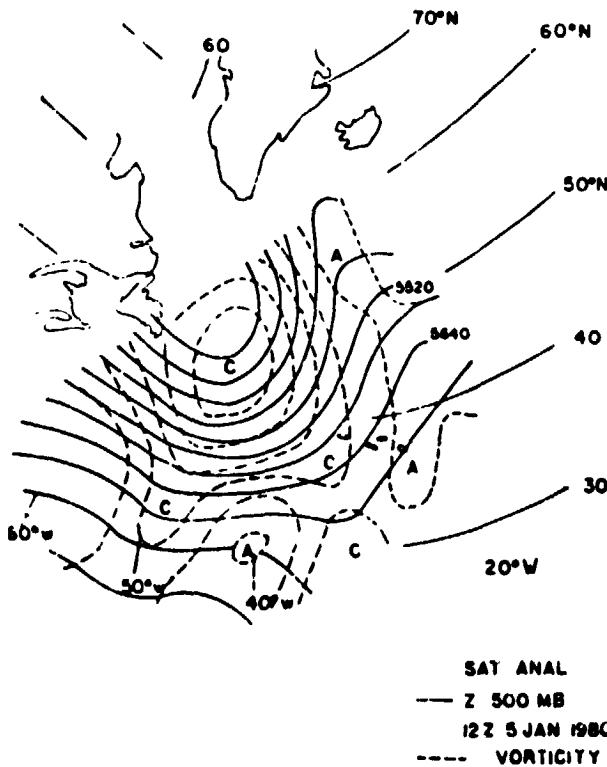


Fig. 2A. Initial 500 mb heights and vorticity for SAT.

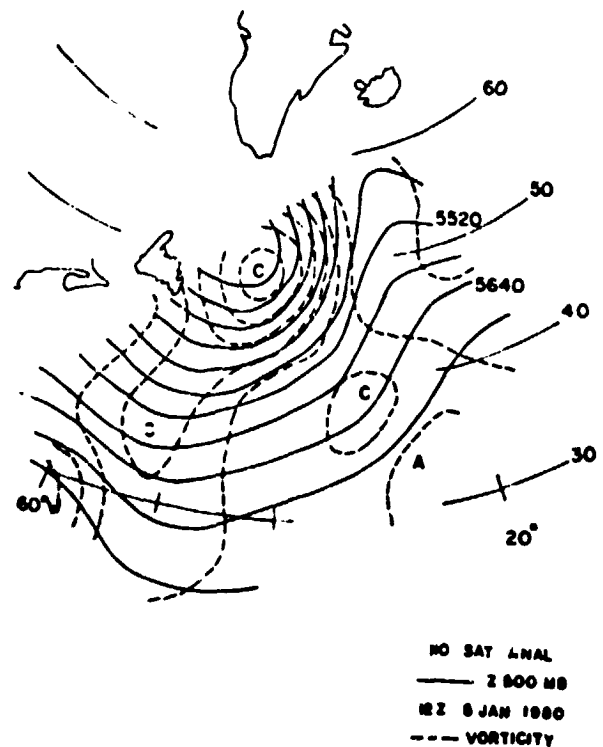


Fig. 2B. Initial 500 mb heights and vorticity for NO SAT.

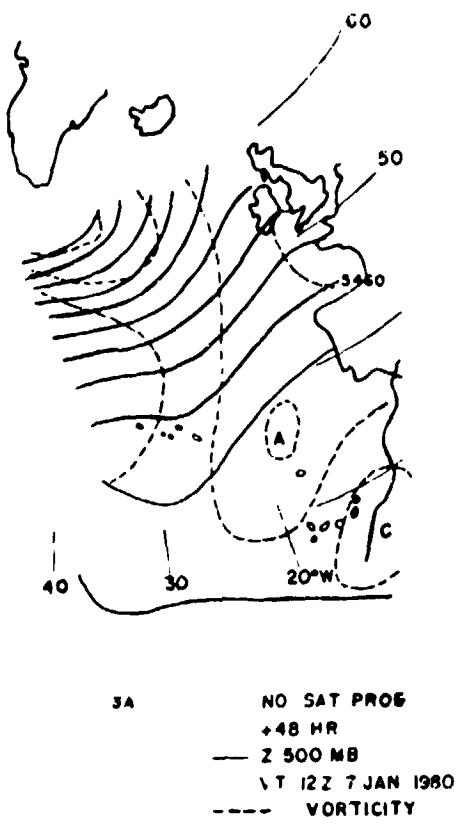


Fig. 3A. 48 hr 500 mb height and vorticity forecast for NO SAT.

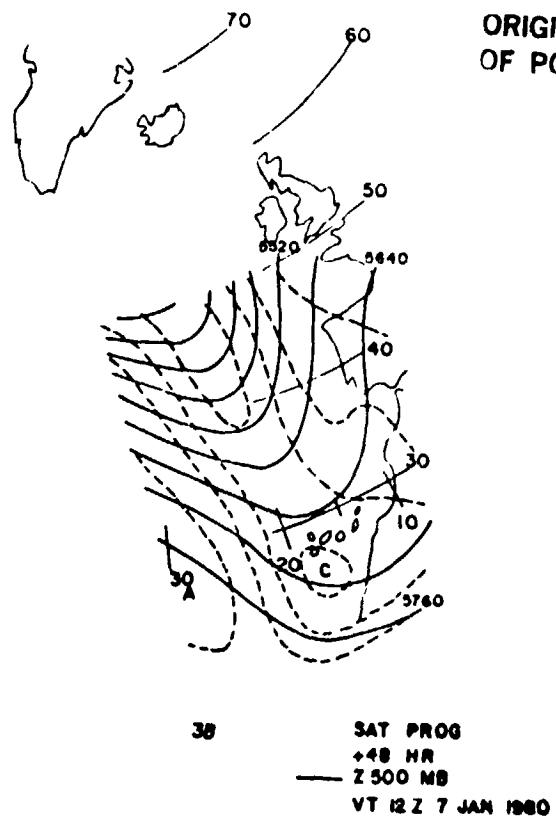


Fig. 3B. 48 hr 500 mb height and vorticity forecast for SAT.

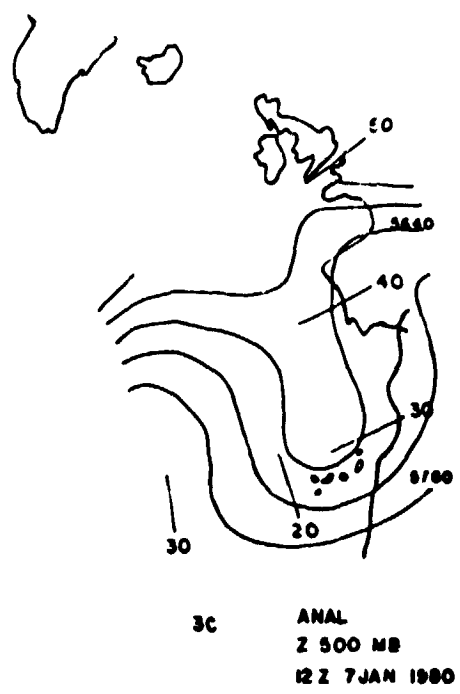


Fig. 3C. Verification 500 mb analysis for 48 hr forecasts.

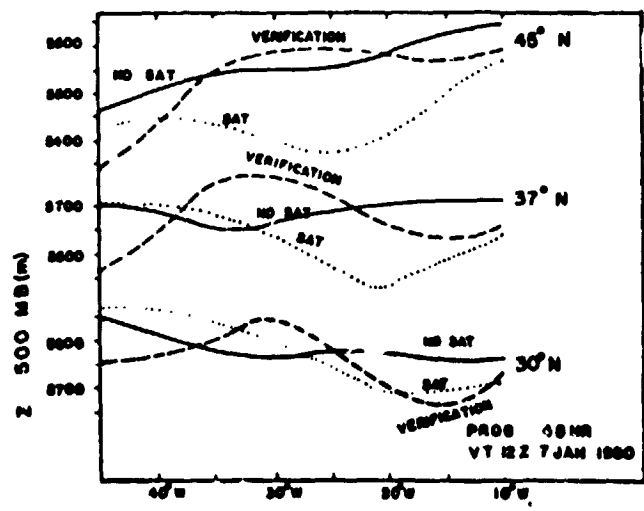


Fig. 4. Longitudinal cross-sections of NO SAT and SAT 48 hr forecasts of 500 mb height versus verification values at selected latitudes.

at 15W. Further south, however, the SAT 500mb prog is clearly superior. It forecasts the trough quite close to its analyzed longitude and correctly places its apex in the vicinity of the Canary Islands where it forecasts a vorticity maximum in contrast to the NO SAT forecast of negative vorticity advection there and a vorticity minimum where the trough ought to be, north of the islands. The NO SAT trough instead lags to the west by some  $13^{\circ}$  longitude. Over the coastal waters of northwest Africa the SAT prog is within 30m of the verification while the NO SAT is more than 110m too high. Figure 4 shows height-longitude cross-sections of the 48hr forecast and analyzed 500mb pressure surface for three representative latitudes. This depiction emphasizes the spurious deepening of the SAT forecast in the northeast alongside the positive impact over the southeast. The positive impact can be related to the initially greater PVA at low latitudes ahead of the short wave (figure 2A, 48hr) due to the inclusion of satellite temperatures in the initial specification. It is interesting to note that surface observations report some shower activity and Cb clouds at the southern end of the trough, weather more consistent with the SAT prog.

#### 4. CASE 2, INITIAL CONDITIONS 12CMT 13 JAN 1979

In the series of experiments from which this case was taken, satellite temperatures observed from 3hr before to 6hr after synoptic time were assimilated to create SAT initial conditions. The wider window was necessary to assure adequate satellite coverage over the Atlantic Ocean. In the case at hand, dense coverage was obtained west of 50W with the result of changing the position and structure of a cold tongue southeast of Newfoundland. Colder satellite temperatures downstream (up to 100m in thickness colder) defined a new axis position which is northeast of the NO SAT position. Moreover, satellite thicknesses are up to 120m warmer to the rear of the trough making the SAT version sharper. The SAT initialization therefore changes the trough position and also decreases its wave length giving it a higher vorticity maximum.

After 48hr the Atlantic trough is oriented north-south along about 27.5W. Positive vorticity advection has moved eastward to the south of Iceland and the downstream ridge is at  $0^{\circ}$  longitude over the North Sea, slanting SSE across the British Isles to Spain. At sea-level the coastal ridge reaches from Scandinavia to central Europe. The cyclonic vorticity over the northern part of the ocean tilts to the northeast down to an open sea-level pressure trough from Iceland to Scotland.

The NO SAT 48hr 500mb forecast erroneously predicts a strong ridge from Greenland to Iceland to the southeast Atlantic. This happens to be the verified position of the trough! The northern British Isles, which should be downstream or an approaching trough are instead kept under the fair-weather downstream side of the upper ridge and directly under the sea-level ridge. Here the Atlantic trough is forecast along about 40W aloft and about 25W at sea-level.

The SAT prog is better in several important respects. Although here too the northern part of the forecast ridge lags too far west, its predicted position over the British Isles is fairly accurate and its sea-level ridge is correctly moved eastward so that the area of the British Isles verges on approaching cyclonic flow. The difference in the forecasts is a consequence of the accelera-

tion eastward of the SAT trough and ridge system during the first 24hr of the forecast. The phase difference between the two forecast modes explains why ridging was replaced by troughing west of the British Isles in the SAT prog and not in its counterpart.

The different circulation forecasts imply different weather forecasts for the British Isles. The weather over the British Isles at the time of the initial conditions was fair due to a sea-level high pressure system which was under an area of likely subsidence east of the upper ridge axis. As the anticyclonic system drifted eastward, southwest England and Ireland came under the influence of over-running from an approaching warm front advected by the southwest flow west of the upper ridge line. Rain was already observed ahead of the front by 06GMT 14 Jan and it spread to northern England and Scotland within the next 24hr. The analyses show that the warm front moved northeastward ahead of the strong southwesterlies aloft and was positioned under the 500mb ridge axis which also marked the western boundary of a large 500mb temperature gradient. The advantage offered by the SAT prog which correctly brings the ridge line to the British Isles by 14 Jan, while the NO SAT fails to do this even by 15 Jan, is that it provides the guidance for a superior weather forecast. The correct association of the warm front and its precipitation pattern with the upper ridge axis in the initial conditions could have led to a correct forecast of rain onset on 14 Jan based on the SAT prog but not the NO SAT.

In this case the satellite data responsible for the positive forecast impact were observed over the Atlantic Ocean 5½hr after the synoptic time. Since the cold tongue was moving eastward quality temperature observations from more than 5hr after the designated time of initialization should have "seen" the trough further downstream than the analysis constructed from the first guess field plus a sparse coverage of radiosonde observations. It is therefore difficult to separate the impact from satellite data per se from any advantage realized by blending late data into the analysis in a synoptically sensitive region. Either way the satellite's advantage as a source of time-continuous data is demonstrated.

##### 5. CASE 3, INITIAL CONDITIONS 12G 21 1979

Comparison of the 1000-500mb thickness patterns of the initial conditions shows that the satellite data defined warmer conditions in the lower troposphere over much of the Atlantic Ocean. A swath of satellite observed temperatures taken very close to the synoptic time initialized the thicknesses some 60-100m higher than in the NO SAT analysis over a large area southeast of Newfoundland and some 60-90m higher near southern Greenland. These differences between the SAT and NO SAT initial conditions occur on the eastern flank of a cold trough which extends from northeast Canada southward to the western Atlantic. The higher thicknesses east of the trough in the SAT version make the cold tongue sharper and move it slightly west of the NO SAT position, especially southwest of Greenland. The cyclonic curvature is somewhat flattened in the NO SAT representation near southern Greenland.

The verification after 48hr shows development of the trough into a deep baroclinic system near southeast Greenland. A sea-level low is analyzed just west of Iceland and is reflected aloft by the sharp 500mb trough slightly further west and oriented north-south along 35°. East of this trough strong southwesterly flow overlies surface northwesterlies indicating strong cold advection from 35W to 20W. Still further to the east, northwest of the British Isles, the pattern

changes to one of weak warm advection.

Neither system predicts the sea-level cyclone near Iceland and this undoubtedly reflects an inadequacy of the numerical model. Similarly, the model does not predict a very sharp trough at 500mb. However, the SAT prog does show a somewhat broader trough slightly downstream of the analyzed position. The NO SAT prog, on the other hand, predicts an even less sharp trough which is much too far east. Its heights are up to 350m too low in this region while the SAT errors do not exceed 200m.

The NO SAT 48hr sea-level prog shows a sharp trough east of its upper-air position; it is predicted to have traversed Scotland leading a wedge of cold air advection which is therefore forecast over the northern British Isles. Observations show that this area is far ahead of the cold air at the verification time and the cold front actually reaches the British Isles only a day later. The more upstream position of the SAT forecast upper trough finds similar expression in its 48hr sea-level prog. Here, the cold air advection zone, while some  $10^{\circ}$  longitude too far east, nevertheless reaches only to about 8W; this predicted cold front bisects Ireland but the prog keeps the cold air west of Scotland. One practical impact of the satellite data is therefore the delay in the forecast incursion of cold air over the northern British Isles.

In summary, satellite observed temperatures apparently corrected the too cold initial NO SAT specification east of a major trough system over the Atlantic. The poorer specification combined with model inadequacies caused a more rapid propagation of vorticity than observed. Moreover, the larger zonal component of the upper flow produced a more tilted and faster moving wedge of cold air whose predicted arrival over the British Isles was about 24hr too early. Although the SAT forecast showed the symptoms of the model error, its better initial specification mitigated the timing error leading to a superior 48hr forecast.

## 6. CONCLUSIONS

The study has shown several examples of the impact of NOAA 6 and TIROS N temperature observations on IMS numerical circulation forecasts. Impacts were traced to the differences that the satellite data made in the initial specification of the atmospheric state. The differences in the progs were shown to be an improvement over several geographic areas and to constitute a degradation over at least one area. These case studies support the previous finding that the ocean areas offer the greatest potential for positive impact and we would add the requirement that the enhanced specification be made over synoptically sensitive areas. Impacts in the circulation progs was shown to constitute significantly different weather forecast guidance. The potential for satellite temperatures in numerical forecasting should be studied via their impact when and wherever their error statistics can be documented.

## 7. ACKNOWLEDGEMENTS

The research was supported by the Office of Climate and Atmospheric Research, NOAA. The research contract was administered in Israel by Tel-Aviv University.

ORIGINAL PAGE 13  
OF POOR QUALITY

8. REFERENCES

- Atlas, R., M. Chil and M. Halem, 1982: The effect of model resolution and satellite sounding data on GLAS model forecasts. Mon. Wea. Rev. 110, 662.
- Broderick, H., 1980: Structure of a baroclinic zone using TIROS-N retrievals. Preprint Volume, 8th Conf. on Weather Forecasting & Analysis(AMS).
- \_\_\_\_\_, 1981: The impact of TIROS-N soundings on the analysis of a cyclone. Preprint Volume: 5th Conf. on Numerical Weather Prediction(AMS).
- \_\_\_\_\_, 1983a: A case study of the impact of satellite temperature soundings on an analysis/forecast system. NESDIS, unpublished.
- \_\_\_\_\_, 1983b: Case of 12GMT Jan 8, 1980- Europe impact. NESDIS, unpublished.
- \_\_\_\_\_, 1983c: Case of 12GMT Jan 11, 1980- North America Impact. NESDIS, unpublished.
- Gruber, A. and C. Watkins, 1982: Statistical assessment of the quality of TIROS-N and NOAA-6 satellite soundings. Mon. Wea. Rev. 110, 867.
- Ohring, G., 1979: Impact of satellite temperature sounding data on weather forecasting. Bull. Amer. Meteor. Soc. 60, 1142.
- Phillips, N., L. McMillin, A. Gruber and D. Wark, 1979: An evaluation of early operational temperature soundings from TIROS-N. Bull. Amer. Meteor. Soc. 60, 1188.
- Thomasell, Chang, Wolfson, Gruber and Ohring, 1983: The impact of satellite soundings and their distribution on forecast accuracy. NESDIS, unpublished.